CHAPTER 200 HYDROLOGY

SECTION 201 BASIC POLICIES AND REQUIREMENTS

The following section provides a list of all design policies which must be applied during a hydrologic analysis performed within Marion County under the jurisdiction of the Department of Capital Asset Management.

201.01
Definitions

Following are discussions of concepts which will be important in a hydrologic analysis. These concepts will be used throughout the remainder of this chapter in dealing with different aspects of hydrologic studies.

Antecedent Moisture Condition:
Antecedent soil moisture conditions are the soil moisture conditions of the watershed at the beginning of a storm. These conditions affect the volume of runoff generated by a particular storm event. Notably they affect the peak discharge only in the lower range of flood magnitudes. As the frequency of a flood event increases, antecedent moisture has a rapidly decreasing influence on runoff.

Bridge:
A conveyance structure which is hydraulically short and has a cross sectional flow-through area greater than 100 square feet.

Culvert:
A structure that conveys any flow collected in an open ended pipe (i.e., headwall, flared end section, mitered end), a cross-drain.

Depression Storage:
Depression storage is the natural depressions within a watershed which store runoff. Generally after the depression storage is filled runoff will commence.

Frequency:
Frequency is the average time interval between equal magnitude floods. For example, a 25-year flood has the probability of occurrence of once every 25 years on the average, or a 4 percent chance of occurrence in any given year.

Hydraulic Roughness:
Hydraulic roughness is a composite of the physical characteristics which influence the flow of water across the earths surface, whether natural or channelized. It affects both the time response of a watershed and drainage channel as well as the channel storage characteristics.

Hydrograph:
The hydrograph is a graph of the time distribution of runoff from a watershed.

Hyetograph:	The hyetograph is a graph of the time distribution of rainfall over a watershed.
Infiltration:	Infiltration is a complex process of allowing runoff to penetrate the ground surface and flow through the upper soil surface. The infiltration curve is a graph of the time distribution at which this occurs.
Interception:	Storage of rainfall on foliage and other intercepting surfaces during a rainfall event is called interception storage.
Lag Time (T_l):	The lag time is defined as the time from the centroid of the excess rainfall to the peak of the runoff hydrograph.
Peak Discharge (q_p):	The peak discharge, sometimes called peak flow, is the maximum rate of flow of water passing a given point during or after a rainfall event.
Rainfall Excess:	After interception, depression storage, and infiltration have been satisfied, if there is excess water available to runoff this is the rainfall excess.
Regional Facility:	A "regional" detention/retention (D/R) facility provides flood storage for off-site and/or on-site watershed areas of five (5) acres or larger.
Stage:	The stage of a channel is the elevation of the water surface above some elevation datum.
Storm Drain:	Underground pipe system designed to intercept and convey stormwater runoff to an adequate outlet.
Time of Concentration (t_c):	The time of concentration is the time required for water to flow from the most remote point of the basin to the location being analyzed. Thus the time of concentration is the maximum time for water to travel through the watershed, which is not always the maximum distance from the outlet to any point in the watershed.
Unit Hydrograph:	A unit hydrograph is the direct runoff hydrograph resulting from a rainfall event which has a specific temporal and spatial distribution and which lasts for a specific duration of time (thus there could be a 5-, 10-,

15-minute, etc., unit hydrograph for the same drainage area). The ordinates of the unit hydrograph are such that the volume of direct runoff represented by the area under the hydrograph is equal to one inch of runoff from the drainage area.

Watershed: A drainage area or region consisting of all the land from an identified, delineated or circumscribed drainage divide draining to a single identified drainage outlet or stream mouth.

Symbol Table: To provide consistency within this chapter as well as throughout this manual the following symbols will be used. These symbols were selected because of their wide use in hydrologic publications. In some cases the same symbol is used in existing publications for more than one definition. Where this occurs in this chapter, the symbol will be defined where it occurs in the text or equations.

Symbols	Definition	Units
A	Drainage area	acres
a	Fitting values	-
b	Fitting values	-
C	Runoff Coefficient	-
CN	SCS-runoff curve number	-
D	Duration	hours
DA	Drainage area	mi^2
i	Rainfall intensity	in/hr
I_a	Initial abstraction from total rainfall	in
L	Flow length	ft
N	Fitting values	-
n	Manning roughness coefficient	-
P	Accumulated rainfall	in
P_w	Wetted perimeter	ft
Q	Rate of runoff	cfs
Q_v	Runoff depth	in
q_p	Peak rate of discharge	cfs
R	Hydraulic Radius	ft
S_m	Potential maximum retention	in
S	Slope	ft/ft
SL	Main channel slope	ft/mi
T_L or T	Lag time	hours
T_p	Time to peak	hours
T_t	Travel time	hours
t_c or T_c	Time of concentration	min
V	Velocity	ft/s

201.02
Alternative
Methods

Many hydrologic methods are available. Recommended methods and the circumstances for their use are listed in Section 201.03. If other methods are used, they must first be calibrated to local conditions and

tested for accuracy and reliability. In addition, complete source documentation must be submitted for review and approval by the Department.

**201.03
Hydrologic
Method**

Procedures to determine the quantity of runoff shall depend upon the size of the watershed under analysis as follows:

*   Rational Method

Rational Method may be used for peak runoff estimations when the total watershed areal tributary to the design point is two-hundred (200) acres or less provided analysis of "regional" detention/retention (D/R) facilities is not a required part of the computational procedure.

*   Regression Equations

USGS regression equations may be used for peak flow computations, provided that the watershed to be analyzed is between 0.31 mi^2 and 4,927 mi^2. In addition, these equations apply only to non-urban watersheds.

*   Runoff Hydrographs and Flood Routing

Hydrograph generation and flood routing procedures shall be required when:

1.   The total watershed area tributary to the design point is greater than two-hundred (200) acres;

2.   Detention/retention facilities requiring downstream analysis; or

3.   As required by the Department.

**201.04
Design Storm
Frequencies**

The design storm frequency is the basis for all runoff computations and stormwater facility designs. Selection of the design storm shall conform to criteria set-forth within Table 201-1 below.

TABLE 201-1: Minimum Design Storm Frequencies

Drainage System Type	Return Interval (Post-development Discharge)
Enclosed Storm Drain	10 year
Cross-Pipe/Open Culverts	25 year (1)
Privately Maintained Culverts	10 year (2)

Bridge Structures (watersheds larger than one (1) mi^2)	100 year (3)
Open Channel	10 year
Regulatory Floodways	100 year
Detention/ Retention Basins	(4)
Storm Drain Inlet Grates	10 year

NOTE:

1. Open culverts shall be designed to safely pass the peak discharge from the 25-year storm event without inundating the roadway. An easement must be recorded for the peak discharge from the 25-year storm event flow areas on all contiguous property. During the peak discharge from the 100-year storm event, road overflow shall not exceed seven (7) inches above the centerline crown elevation of the roadway at any point within the watershed. The peak discharge from the 100-year design storm event is to be computed to determine the maximum water surface elevation for the storm event which is to be used in the determination of a floodplain boundary so that a building restriction line can be shown on a record plat. The lowest elevation where water may enter the structure must be outside this delineation.

2. Open culverts located outside of public right-of-way and drainage easement areas may be designed to convey the peak discharge from the 10-year storm event, provided the upstream drainage area does not exceed five (5) acres. For drainage areas greater than five (5) acres the design storm event is the 25-year storm. The peak discharge from the 100-year design storm event is to be computed to determine the maximum water surface elevation for the storm event which is to be used in the determination of a floodplain boundary so that a building restriction line can be shown on a record plat. The lowest elevation where water may enter the structure must be outside this delineation.

3. Shall be in full conformance with the standards of the Indiana Department of Natural Resources (IDNR) Division of Water Resources.

4. Detention/retention basins shall be designed to provide

201.05
Off-site Hydrologic
Analysis

According to Chapter 10 ½, a stormwater facility shall be provided which allows drainage of water runoff from each upper watershed area and from each portion of the parcel to a place or places adequate to receive it.

Additionally:

1.   The part of the stormwater facility situated within the parcel shall drain adequately each and every part of the parcel and shall be sufficient to accept the present water runoff from developed and undeveloped areas upstream.

2.   The part of the water runoff attributable to future development in undeveloped or underdeveloped areas upstream, which is not reasonably likely to be accommodated in such upstream areas shall also be accommodated.

3.   At least one opening shall be provided for each watershed at the upstream edge of the parcel or adjacent properties to accept upstream drainage.

Due to the potential impact of site developments on area-wide drainage, investigation of facilities outside of the site boundaries shall be a required part of the design process except in the case where oversized detention is provided in lieu of downstream analysis as described in Chapter 300. The extent of these analyses shall depend upon the nature of the off-site stormwater facilities, and circumstances unique to each developing property. These guidelines for off-site analysis should be viewed by the designer as a minimum performance standard only, and are not intended to replace engineering judgement. As such, site conditions may dictate a more extensive off-site analysis than that set forth herein.

201.06
When Downstream
Analysis and
Detention/Retention not
Required

For any site analysis of the downstream stormwater system or the provision of detention/retention will not be required for the following:

1.   Downstream facilities which after completion of the land development will not be accepting runoff from the developing property.

2.   Land alterations where the primary basis on which a stormwater permit is required is the construction, enlargement or location, on a permanent foundation, of a one-family dwelling, two-family dwelling or accessory structure appurtenant to either a one- or two-family dwelling.

3.   Approved fill areas which do not increase the amount of

impervious area on-site by more than a total of 0.5 acres, provided the existing runoff patterns and flow capacity of the property will not be altered by the filling operations.

4. Additions to existing commercial buildings, provided the total impervious area on-site, including roof tops, sidewalks, drives and parking lots, is not increased by more than a total of 0.5 acres with no alteration to existing stormwater facilities.

5. Those site developments where the stormwater management system has been designed such that:

    a. after combining flows from both the off-site and on-site drainage areas, there will be no increase in the total peak discharge from the developing site during the 2, 10, or 100 year storm events; and

    b. the volume of runoff for each project site outlet has not been increased for the entire range of storm events, up to the 100 year storm event; and

    c. the flow width and velocity at the property line for each sub-basin is less than or equal to that flow width and velocity which existed prior to the development.

201.07
Downstream Analysis
Requirements

For those development sites which do not meet the requirements of Section 201.06, downstream peak flow increase analysis shall be done. The peak flow analys shall be done for each downstream stormwater facility using the 2, 10, and 100 year design storm frequency.

The downstream analysis shall extend to that point where ten percent (10%) or less of the total watershed area contributing flow to the downstream analysis point originates from the larger of the total site area or the subject detention/retention basin watershed area to that outlet point from the site. It shall include all intermediate tributary stream junction points from the facility outlet point down to the ten percent (10%) point. For example, in the case of a four (4) acre site two (2) of which flow through a detention pond, the downstream analysis should extend to a point where the watershed is larger than forty (40) acres. In the case of a regional facility which receives fifty (50) acres of off-site drainage area and ten (10) acres of on-site developing drainage area, the downstream analysis shall extend to a point where the watershed is larger than six hundred (600) acres. The Department may require a greater distance of downstream analysis than that outlined above based upon a review of individual site conditions.

The stormwater system within the parcel shall be designed such that there will be no increase in peak discharge or runoff rates as a result of the development, down to the ten percent point, unless said downstream facilities located beyond the limits of the parcel are sufficient to accept:

1.   The water runoff from the parcel after development; plus

2.   The present water runoff from developed areas upstream; plus

3.   The present water runoff from undeveloped areas upstream; plus

4.   The present water runoff of those areas through which the stormwater facility passes.

Proposals to direct discharge from a developing site without installation of detention/retention facilities will be reviewed on an individual basis by the Department. Proposals and supporting analysis shall provide documentation that the greatest flood control benefits are realized by direct discharge from the developing property. Review of the type of future land development which is likely to occur within each stormwater basin shall be considered by the Department when making the determination to allow direct discharge, and may be used as justification for requiring installation of detention/retention facilities.

201.08
Actions if Peak Flow
Shows Increase

If downstream facilities are not adequate to receive the increase of runoff attributable to the development one, or a combination, of three actions may be taken:

1.   The site may be redesigned to limit flow increases to acceptable levels (such as changing the internal drainage design or land use layout);

2.   Detention/retention may be provided to reduce peak flows to acceptable levels per Chapter 300 guidance; or

3.   Downstream stormwater conveyance facility improvements can be made to increase the carrying capacity of the system (such as channel enlargement, culvert or storm drain enlargement or improvements, levee construction or other action). Mitigation actions shall be taken, as necessary, downstream to the ten percent point.

201.09
Regional
Facilities and
Upstream
Analysis

A "regional" facility, including detention/retention facilities, storm drains, culverts, and open channels are those which convey or store runoff from on-site and/or off-site watershed areas of total drainage size to the facility of five (5) acres or larger. Off-site watershed areas are those which by virtue of existing topography must outlet through the developing property.

A complete analysis of those upstream watershed areas contributing flow to a proposed stormwater facility shall be required. The peak flow and/or runoff hydrographs from these areas shall be verified through submission of the following information to the Department:

1. A contour map of sufficient scale and detail to accurately depict the watershed boundaries.

2. The drainage area in either acres or square miles.

3. Runoff curve numbers, and time of concentration estimates, with supporting computations, as applicable for each watershed basin.

4. The estimated peak discharge and/or runoff hydrograph for each sub-basin for each design storm frequency analyzed.

5. All pertinent information relating to procedures used to compute runoff within those guidelines set forth herein.

SECTION 202 RAINFALL

**202.01
Rainfall Data**

The rainfall intensity is the average rainfall rate, in inches per hour, for a given frequency, having a duration equal to the time of concentration. The rainfall intensities listed in Table 202-1, and 202-2 shall be used for all hydrologic analysis in Marion County.

After the design storm frequency has been selected in conformance with Chapter 201.04 of this Manual and the total time-of-concentration has been determined as described by Section 203 of this chapter, the rainfall intensity may be determined from Figure 202-1, the rainfall Intensity-Duration-Frequency (IDF) Curve for Indianapolis, Indiana. The intensities based on the appropriate durations and frequencies may also be determined by Equation 202.01 and the coefficients listed in Table 202-1. Equation 202.01 is a standard form for IDF curves. The coefficients were derived from a combination of locally derived data and NOAA isopluvial maps. Contact the Department for more details.

$$i = \frac{a}{(t+b)^N}$$

(Equation 202.01)

where:
i = rainfall intensity (in/hr)
t = time (minutes)
a, b, and N are fitting values listed in Table 202-1

**202.02
Rainfall
Distribution**

Staff has determined that Huff rainfall distributions most accurately reflect Indianapolis conditions. Huff Second Quartile storm distribution fifty percent (50%) probability curve or column shall be used for hydrograph computations, as is applicable for the design methodology. Figure 202-2 and Table 202-3 can be referenced for the appropriate distribution.

202.03	Storm durations for stormwater facility design where runoff hydrograph
Design	analysis and flood routing techniques are a required part of the design
Storm Duration	process shall conform to the following guidelines:

202.03
Design
Storm Duration

Storm durations for stormwater facility design where runoff hydrograph analysis and flood routing techniques are a required part of the design process shall conform to the following guidelines:

1.   For peak discharge determination, a storm duration equal to or greater than the site time-of-concentration shall be used.

2.   For detention/retention pond design, storm durations that maximize the peak discharges for the pre-developed and post-developed conditions shall be used for modified rational method design,

3.   For detention/retention pond design, a storm duration that maximizes the peak discharge for the pre-developed condition and a storm duration that maximizes required detention / retention volume for the post-development condition shall be used for the standard hydrogaph routing method of detention design.

In no case shall a storm duration less than 30 minutes be used with the Huff distribution either in peak flow or detention/retention design.

SECTION 203 DETERMINING TIME-OF-CONCENTRATION (T_c)

203.01
Definition

The basin time-of-concentration is defined as the time required for water to flow from the most remote part of the drainage area to the point under design.   The time-of-concentration is computed as a summation of travel times within each flow path as follows:

$$T_c = T_t + T_t + \ldots T_m$$

(Equation 203.01)

where: T_c = time of concentration (hours)
          m = number of flow segments

For typical urban areas, the time of concentration consists of an overland flow time, shallow concentrated flow, plus the time of travel in the storm drain, paved gutter, roadside ditch, or drainage channel. The time of concentration shall be the longest sub-basin travel time when all flow paths are considered. A form for time of concentration computations (Figure 203-1) is presented in the Appendix.

203.02
Minimum Time of
Concentration

The minimum time of concentration for all computations shall be 5 minutes.

203.03
Overland Flow

Overland flow in urbanized basins occurs from the backs of lots to the street, across and within parking lots and grass belts, and within park

Time

areas. Overland flow over plane surfaces for distances of less than 300 lineal feet (100 feet for paved surfaces) may be calculated using Manning's kinematic solution (Overton and Meadows 1976) to compute T_t. This information has been adapted for Indianapolis from SCS TR-55, "Urban Hydrology For Small Watersheds" (Second Ed., June 1986) as follows:

$$T_t = \frac{0.0043(nL)^{0.8}}{S^{0.4}}$$

(Equation 203.02)

where:
T_t = travel time (hr)
n = Manning's roughness coefficient (Table 203-1)
L = flow length (ft), and
S = land slope, (ft/ft)

Table 203-1 summarizes Manning's n values required within Equation 203.02. The Manning's n values listed within Table 203-1 are to be used within Equation 203.02 only, and not as a part of open channel design.

203.04
Shallow Concentrated
Flow

After a maximum of 300 feet (100 feet for paved areas), overland flow will normally become shallow concentrated flow. The average velocity of this flow can be determined from Figure 203-2, in which average velocity is a function of watercourse slope and type of channel. For slopes less than the minimum in the Figure (0.005 ft/ft) the following equations (depicted in the Figure) can be used:

Unpaved

$$V = 16.1345(S)^{0.5}$$

(Equation 203.04)

Paved

$$V = 20.3282(S)^{0.5}$$

(Equation 203.05)

where:
V = average velocity (ft/s), and
S = slope of hydraulic grade line (watercourse slope, ft/ft)

203.05
Paved Gutter and Open
Channel Flow

The travel time within the storm drain, gutter, swale, ditch, or other drainage way can be determined through an analysis of the hydraulic properties of these conveyance systems as bankfull or pipe full using Manning's equation, which follows:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

(Equation 203.06)

where:
V = average velocity (ft/s)
R = hydraulic radius (ft) and equals A/P_w
A = cross sectional flow area (sq.ft.)
P_w = wetted perimeter (feet)
S = slope of energy grade line (channel slope, ft/ft), and
n = Manning's roughness coefficient for open channel flow

Values of Manning's "n" for use in Manning's equation may be obtained from standard design textbooks such as Chow (1959) and Linsley et al. (1962). These values are also included as a part of discussion of Manning's equation within Chapter 300 of this Manual, "Stormwater Hydraulics".

Figure 203-3 presents a nomograph for computation of open channel flow velocities through use of Manning's equation (Equation 203.06).

Storm drain flow time is typically calculated by choosing a pipe or channel configuration and calculating the flow velocity (V). This time is then found by the following:

$$T_t = \frac{L}{60V}$$

(Equation 203.07)

where:
T_t = travel time in pipe (min)
L = reach length (ft)
V = velocity in reach (ft/sec) = Q/A

SECTION 204 PEAK FLOW COMPUTATIONS

204.01
Introduction

Peak flow value estimates can be made using either peak-flow-only methods (discussed in this section) or methods which generate the total outflow hydrograph (peak, volume and timing of the flow) discussed in the next section.

204.02
Rational
Formula

Peak discharges for watershed areas less than two-hundred (200) acres may be computed using the Rational Method. The Rational Method is based upon the following equation:

$$Q = CiA$$

(Equation 204.01)

where:

Q = peak discharge (cubic feet per second or cfs)

C = the runoff coefficient, or the ratio of peak runoff rate to average rainfall rate over the watershed during the time of Concentration (t$_c$)

i = the rainfall intensity (inches/hour)

A = the contributing area of watershed under consideration (acres)

Where distinctive land use features are known, use of a composite or "weighted" C factor shall be required. Runoff coefficients for use within the Rational Method are summarized within Table 204-1.

**204.03
Regression
Equations**

Discharge estimates can be computed using the regression equations published in the USGS document "Techniques for Estimating Magnitude and Frequency of Floods on Streams in Indiana". These equations are to be used on unregulated, non-urban streams. The equations are valid for ranges of basin characteristics listed below in the statistics of the regression analysis.

$$Q_2 = 47.85DA^{0.758}SL^{0.273}$$

(Equation 204.02)

$$Q_{10} = 69.05DA^{0.772}SL^{0.384}$$

(Equation 204.03)

$$Q_{25} = 79.00DA^{0.776}SL^{0.423}$$

(Equation 204.04)

$$Q_{50} = 86.44DA^{0.777}SL^{0.445}$$

(Equation 204.05)

$$Q_{100} = 93.22DA^{0.779}SL^{0.466}$$

(Equation 204.06)

where:

DA = drainage area (square miles)

SL = main channel slope between the 10 and 85 percent of the distance from the point of interest to the basin divide (feet/mile)

The statistics of the basin characteristics and associated limitations of the equations are presented in the following table.

Basin Characteristics	Maximum	Minimum
DA	4,927 mi^2	0.31 mi^2
SL	149 ft/mi	2.0 ft/mi

SECTION 205 HYDROGRAPH GENERATION METHODS

205.01
SCS Method Reference

The following information has been developed from information contained within Chapter 4 of the USDA Soil Conservation Service (SCS) National Engineering Handbook (NEH-4) or FHWA publication Hydraulic Engineering Circular # 19, "Hydrology". This document should be referenced for further information.

205.02
SCS Method Formulas

The major factors that determine the runoff curve number are the hydrologic soil group (HSG), cover type, land treatment, hydrologic condition, and antecedent runoff condition. The SCS runoff equation is as follows:

$$Q_v = \frac{(P-I_a)^2}{(P-I_a)+S_m}$$

(Equation 205.01)

where:
Q_v = runoff (inches)
P = rainfall (inches)
S_m = potential maximum retention after runoff begins
I_a = initial abstraction

The SCS has found the I_a to be approximated by the following empirical equation:

$$I_a = 0.2S_m$$

(Equation 205.02)

By substituting Equation 205.02 into Equation 205.01, the following runoff equation is derived:

$$Q_v = \frac{(P-0.2S_m)^2}{P+0.8S_m}$$

(Equation 205.03)

The value of S_m is related to the soil and cover conditions of the watershed through the CN. The value of CN has a range of 0 to 100, and S_m is related to CN by the following equation:

$$S_m = (1000/CN) - 10$$

(Equation 205.04)

205.03
SCS Curve Numbers

Runoff curve numbers are derived from comparisons of different combinations of the ultimate abstraction (S) and the rainfall depth (P). Soils are classified into four Hydrologic Soils Groups (HSG's) according

to their minimum infiltration rate.

The hydrologic grouping of Marion County soils, as well as other soil and water features are summarized within Table 205-1. The USDA Soil Conservation Service "Soil Survey for Marion County, Indiana" should be referenced for additional soils information. Tables 205-2, 205-3 and 205-4 may be referenced for information regarding determination of runoff curve numbers for various land uses and hydrologic soil groups. Where distinctive land features are known, use of a composite or "weighted" curve number shall be required. A form for weighted curve number computations (Figure 205-1) is presented in the Appendix.

205.04
SCS Unit Hydrographs

The USDA Soil Conservation Service (SCS) has developed methods of calculating runoff for any storm, by subtracting infiltration and other losses from rainfall depth to obtain precipitation excess (Reference SCS National Engineering Handbook, Chapter 4 [NEH-4]). Two types of hydrographs are used in the SCS procedure, dimensionless hydrographs and composite hydrographs.

A unit hydrograph, Figure 205-2 represents the time distribution of flow resulting from one inch of direct runoff occurring over the watershed in a specified time. Unit hydrograph time and discharge ratios are shown in Table 205-5. The SCS method uses the dimensionless unit hydrograph, as defined in NEH-4, to develop incremental hydrographs for small durations of the total design storm. These incremental hydrographs are then combined into a composite hydrograph for the drainage area.

Characteristics of the dimensionless hydrograph vary with the size, shape, and slope of the tributary drainage area. The most significant characteristics affecting the dimensionless hydrograph shape are the basin lag and the peak discharge for a given rainfall. Basin lag in this method is defined as the time from the center of mass of rainfall excess to the hydrograph peak. The following equation is used to determine basin lag time:

$$T_L = 0.6 T_c$$

(Equation 205.05)

where:
T_L = basin lag time (hours)
T_c = time of concentration (hours)

The following equations should be used in conjunction with Table 205-5 to determine the shape of the unit hydrograph.

$$T_p = (D/2) + T_L$$

(Equation 205.06)

where:

T_p = time to peak (hours)

D = duration of excess unit rainfall (hours)

T_L = lag time of the watershed from Equation 205.05 (hours)

$$q_p = \frac{484AQ_v}{T_p}$$

(Equation 205.07)

where:

A = watershed area (square miles)

Q_v = direct runoff from Equation 205.03 (inches)

T_p = time to peak from Equation 205.6 (hours)

q_p = peak discharge (cfs)

The unit hydrographs are applied to the incremental runoff values for the storm event through a process described as convolution to result in a design hydrograph. The process of convolution is described in the publication NEH-4.

Return Period	a	b	N	R^2
2	32.852	7	0.7780	0.99966
5	46.060	8	0.7859	0.99958
10	56.974	9	0.7953	0.99952
25	72.739	10	0.8115	0.99942
50	84.475	11	0.8147	0.99940
100	92.718	11	0.8145	0.99942

TABLE 202-1: IDF Equation Values for Indianapolis, IN

Hours	Minutes	Return Period - Rainfall Intensity (in/hr)					
		2	5	10	25	50	100
0.08	5	4.75	6.14	6.99	8.08	8.83	9.69
0.17	10	3.63	4.75	5.48	6.40	7.07	7.77
0.25	15	2.97	3.92	4.55	5.34	5.94	6.53
0.5	30	1.98	2.64	3.09	3.65	4.10	4.50
1	60	1.25	1.67	1.96	2.31	2.62	2.88
2	120	0.76	1.02	1.20	1.40	1.59	1.75
3	180	0.56	0.75	0.88	1.03	1.17	1.29
6	360	0.33	0.44	0.52	0.60	0.68	0.75
12	720	0.20	0.26	0.30	0.35	0.39	0.43
24	1440	0.11	0.15	0.17	0.20	0.22	0.25

Hours	Minutes	Return Period - Rainfall Depth (in)					
		2	5	10	25	50	100
0.08	5	0.40	0.51	0.58	0.67	0.74	0.81
0.17	10	0.61	0.79	0.91	1.07	1.18	1.30
0.25	15	0.74	0.98	1.14	1.34	1.49	1.63
0.5	30	0.99	1.32	1.55	1.83	2.05	2.25
1	60	1.25	1.67	1.96	2.31	2.62	2.88
2	120	1.52	2.04	2.40	2.80	3.18	3.50
3	180	1.68	2.25	2.64	3.09	3.51	3.87
6	360	1.98	2.64	3.12	3.60	4.08	4.50
12	720	2.40	3.12	3.60	4.20	4.68	5.16
24	1440	2.64	3.60	4.08	4.80	5.28	6.00

TABLE 202-2: IDF and IDD Tables for Indianapolis, IN

FIGURE 202-1: Indianapolis IDF Curve
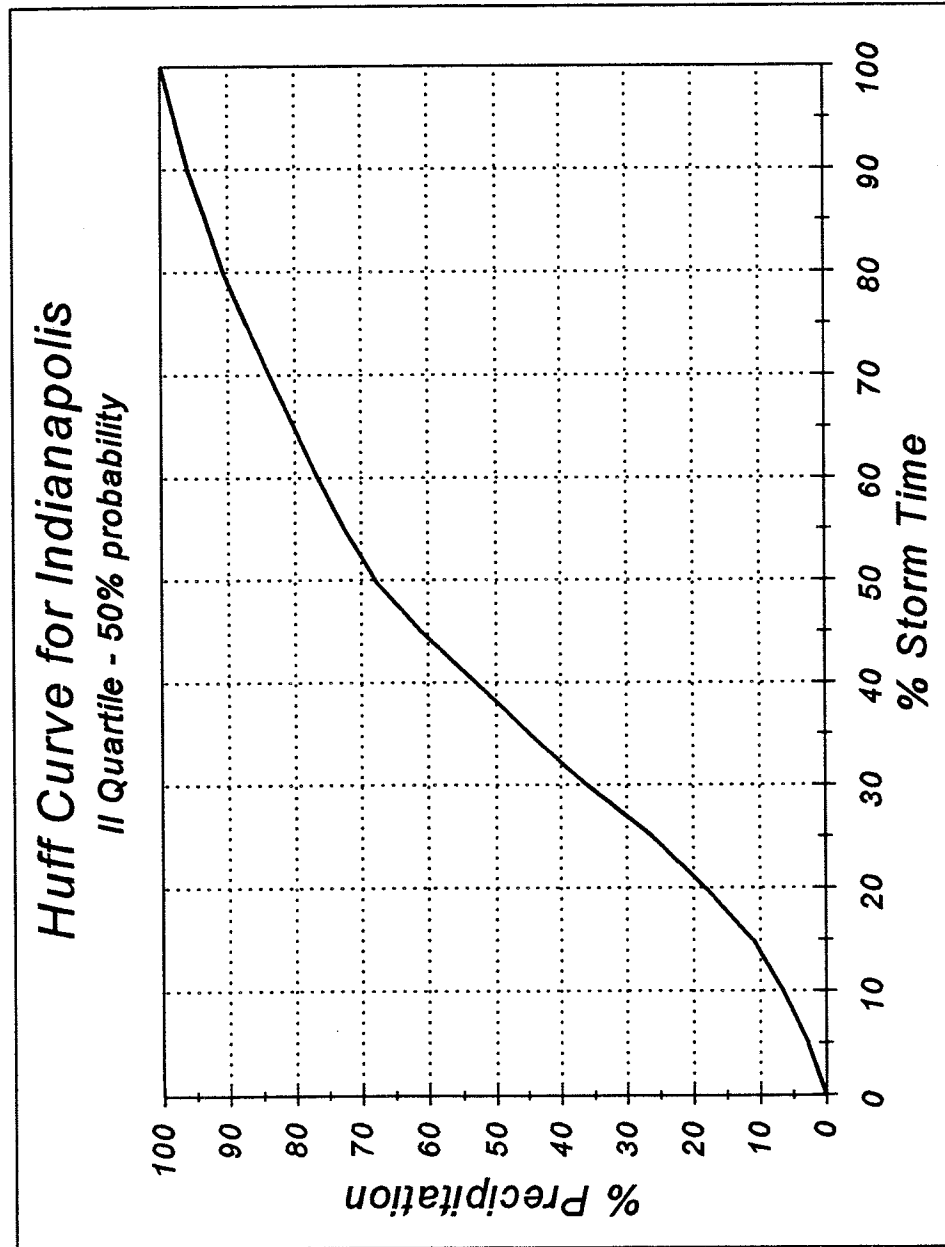
FIGURE 202-2: Second Quartile Huff Rainfall Distribution
(SOURCE: Purdue, et al, "Statistical Characteristics of Short Time Increment Rainfall")

% Storm Time	% Precipitation
0	0.0
5 ·	2.7
10	6.5
15 ·	11.0
20	18.1
25 ·	26.0
30	35.9
35 ·	44.7
40	52.9
45 ·	61.0
50	67.9
55 ·	72.5
60	76.5
65 ·	80.2
70	83.8
75 ·	87.2
80	90.7
85 ·	93.3
90	95.9
95 ·	97.9
100	100.0

· Estimated Values

TABLE 202-3: Huff Curve Ordinates
(SOURCE: Purdue, et al, "Statistical Characteristics of Short Time Increment Rainfall")

Project _____ By _____ Date _____

Location _____ Checked _____ Date _____

Circle one: Present Developed _____

Circle one: T_c T_t through subarea _____

NOTES: Space for as many as two segments per flow type can be used for each worksheet.

Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)   Segment ID

1. Surface description   ....

2. Manning's roughness coeff., n   ..

3. Flow length, L (total L $\leq$ 300 ft) ....   ft

4. Two-yr 24-hr rainfall, P_2 ....   in

5. Land slope, s .... ft/ft

6. $T_t = \dfrac{0.007\ (nL)^{0.8}}{P_2^{0.5}\ s^{0.4}}$ Compute T_t ......   hr

[table] + [ ] = [ ]

Shallow concentrated flow   Segment ID

7. Surface description (paved or unpaved) .....

8. Flow length, L ....   ft

9. Watercourse slope, s .... ft/ft

10. Average velocity, V   .... ft/s

11. $T_t = \dfrac{L}{3600\ V}$ Compute T_t ......   hr

[table] + [ ] = [ ]

Channel flow   Segment ID

12. Cross sectional flow area, a ....   ft^2

13. Wetted perimeter, p_w ....   ft

14. Hydraulic radius, $r = \dfrac{a}{p_w}$ Compute r ....   ft

15. Channel slope, s .... ft/ft

16. Manning's roughness coeff., n ....

17. $V = \dfrac{1.49\ r^{2/3}\ s^{1/2}}{n}$ Compute V .... ft/s

18. Flow length, L ....   ft

19. $T_t = \dfrac{L}{3600\ V}$ Compute T_t ......   hr

[table] + [ ] = [ ]

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) .... hr [ ]

FIGURE 203-1: Time of Concentration or Travel Time Worksheet
(SOURCE: 210-VI-TR-55, Second Ed., June 1986)

Surface Description	n
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils:	
Residue cover </= 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods:	
Light underbrush	0.40
Dense underbrush	0.80

TABLE 203-1: Roughness coefficients (Manning's n) for sheet flow
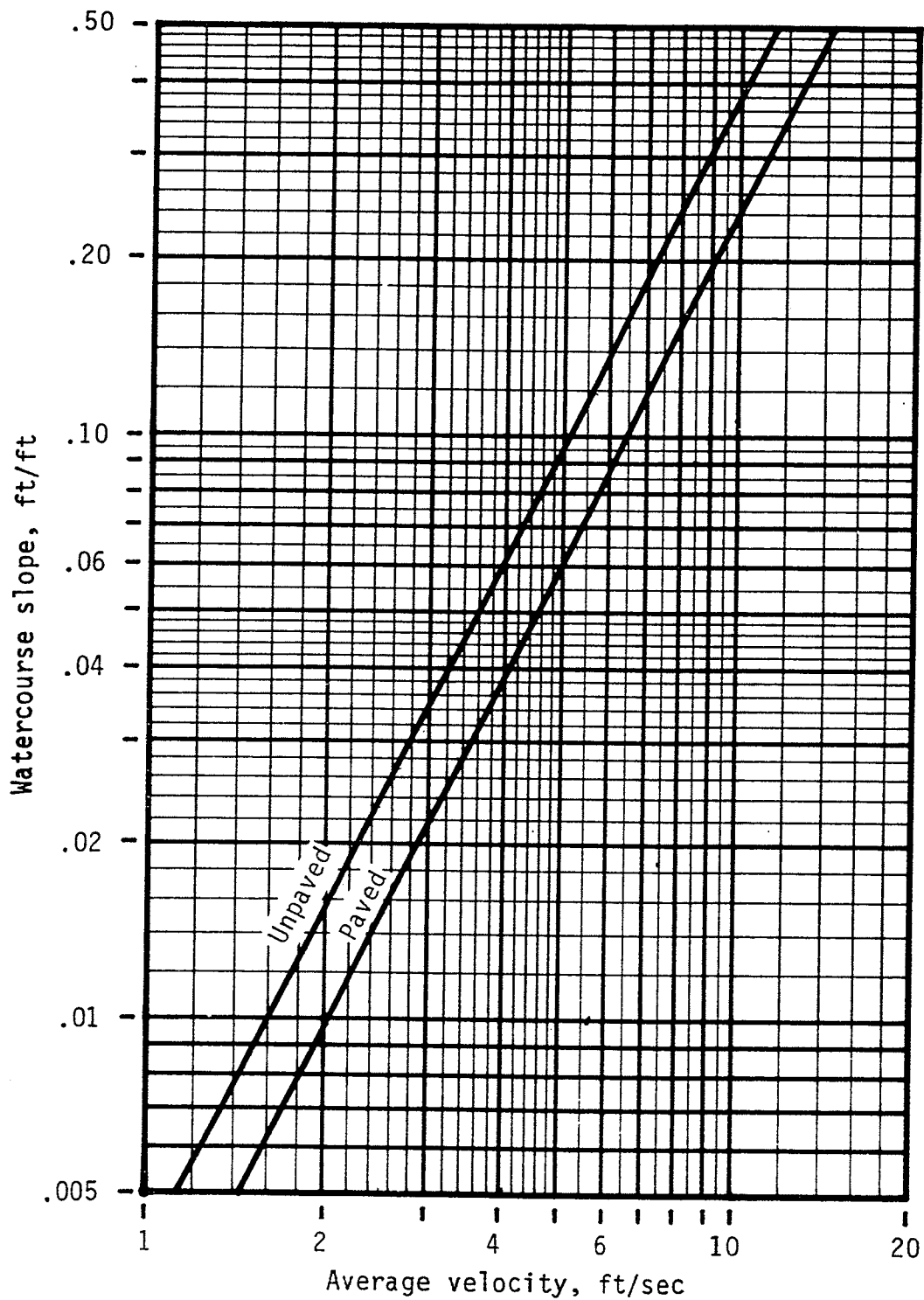
FIGURE 203-2: Average Velocities for Estimating Travel Time for Shallow Concentrated Flow
(SOURCE: 210-VI-TR-55, Second Ed., June 1986)
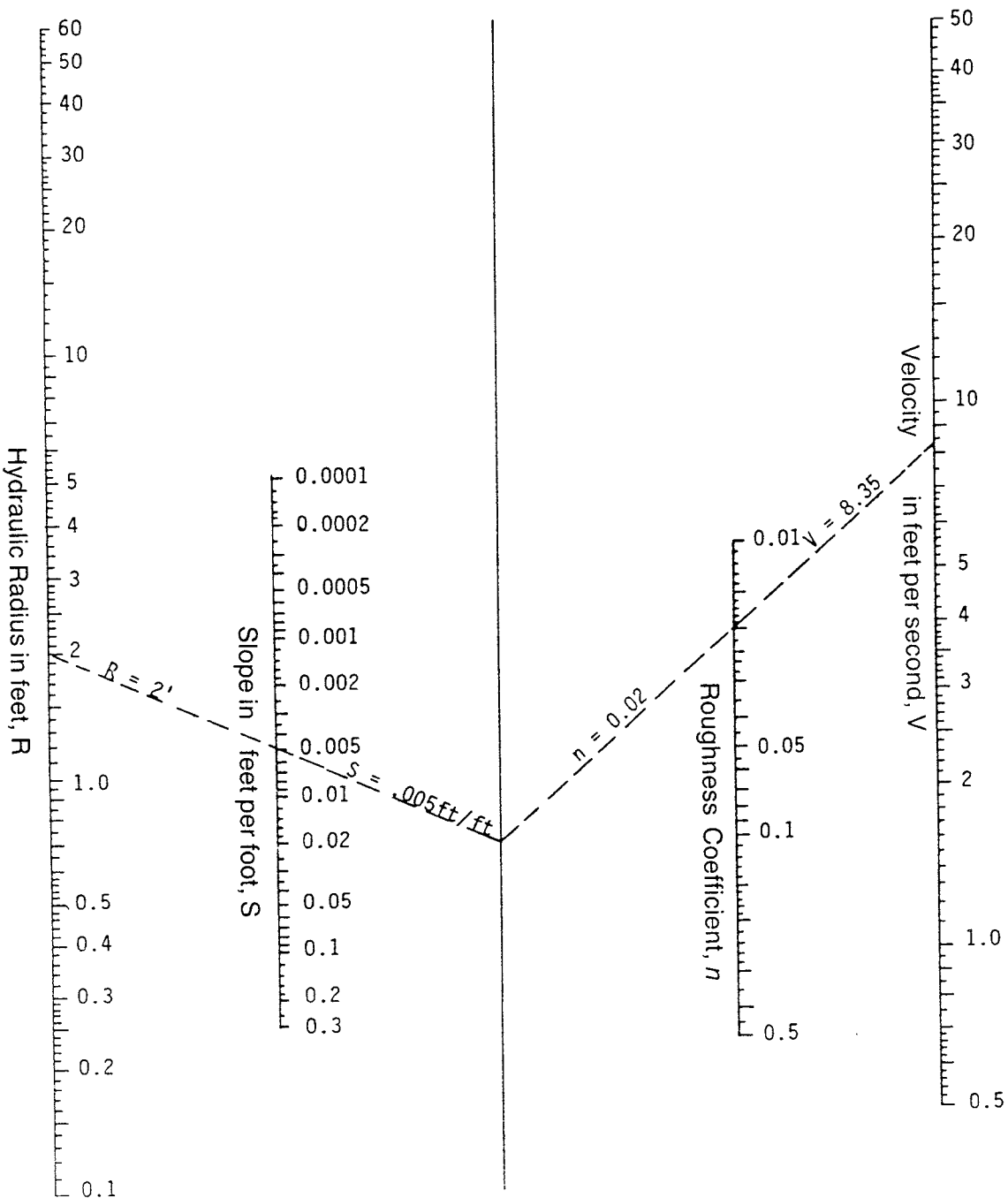
FIGURE 203-3: Nomograph for Solution of Manning Equation
(SOURCE: North Carolina Erosion & Sediment Control Planning & Design Manual, 09/01/88)

TYPE OF SURFACE		RUNOFF COEFFICIENT [c]
Non-Urban Areas		
Bare earth		0.55
Steep grassed areas (slope 2:1)		0.60
Turf meadows		0.25
Forested areas		0.20
Cultivated fields		0.30
Urban Areas		
All watertight roof surfaces		0.90
Pavement		0.85
Gravel	0.85	
Impervious soils (heavy)		0.55
Impervious soils (with turf)		0.45
Slightly pervious soil		0.25
Slightly pervious soil (with turf)	0.20	
Moderately pervious soil		0.15
Moderately pervious soil (with turf)		0.10
Business, Commercial & Industrial		0.85
Apartments & Townhouses		0.70
Schools & Churches		0.55
Single Family Lots < 10,000 SF		0.45
Lots < 12,000 SF		0.45
Lots < 17,000 SF		0.40
Lots > ½ acre	0.35	
Park, Cemetery or Unimproved Area		0.30

TABLE 204-1: Runoff Coefficients [c] for Use in the Rational Method

Soil and water features

[Absence of an entry indicates the feature is not a concern. The symbol < means less than; > means greater than]

Soil name and map symbol	Hydro-logic group	Flooding			High water table			Potential frost action
		Frequency	Duration	Months	Depth	Kind	Months	
Brookston:					*Ft*			
Br	B/D	Frequent	Brief	Dec–May	0–1.0	Apparent	Dec–May	High.
Crosby:								
CrA	C	None			1.0–3.0	Apparent	Jan–Apr	High.
¹ CsB2:								
Crosby part	C	None			1.0–3.0	Apparent	Jan–Apr	High.
Miami part	B	None			>6.0			Moderate.
Eel:								
Ee	C	Frequent	Brief	Oct–Jun	3.0–6.0	Apparent	Jan–Apr	High.
Fox:								
FoA, FoB2, ¹ FxC2	B	None			>6.0			Moderate.
Genesee:								
Ge	B	Frequent	Brief	Oct–Jun	>6.0			Moderate.
Hennepin:								
HeF	B	None			>6.0			Moderate.
Martinsville:								
MgA, MgB2	B	None			>6.0			Moderate.
Miami:								
MmA, MmB2, MmC2, ¹ MxD2, MxE2.	B	None			>6.0			Moderate.
Ockley:								
OcA, OcB2	B	None			>6.0			Moderate.
nsselaer:								
Re	B/D	None			0–1.0	Apparent	Dec–May	High.
Shoals:								
Sh	C	Frequent	Brief	Oct–Jun	1.0–3.0	Apparent	Jan–Apr	High.
Sleeth:								
Sk	C	None			1.0–3.0	Apparent	Jan–Apr	High.
Sloan:								
Sn	B/D	Frequent	Long	Oct–Jun	0–0.5	Apparent	Nov–Jun	High.
Urban land:								
¹ Ub:								
Brookston part	B/D	Frequent	Brief	Dec–May	0–1.0	Apparent	Dec–May	High.
¹ Uc:								
Crosby part	C	None			1.0–3.0	Apparent	Jan–Apr	High.
¹ UfA:								
Fox part	B	None			>6.0			Moderate.
¹ UfC:								
Fox part	B	None			>6.0			Moderate.
¹ Ug:								
Genesee part	B	Frequent	Brief	Oct–Jun	>6.0			Moderate.
¹ UmB:								
Miami part	B	None			>6.0			Moderate.
¹ UmC:								
Miami part	B	None			>6.0			Moderate.
¹ Uw:								
Westland part	B/D	Frequent	Brief	Dec–May	0–1.0	Apparent	Dec–May	High.
Westland:								
We	B/D	Frequent	Brief	Dec–May	0–1.0	Apparent	Dec–May	High.
Whitaker:								
Wh	C	None			1.0–3.0	Apparent	Jan–Apr	High.

¹ This mapping unit is made up of two or more dominant kinds of soil. See mapping unit description for the composition and .lavior of the whole mapping unit.

TABLE 205-1: Soil and Water Features for Marion County, Indiana

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D

Fully developed urban areas (vegetation established)

Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:

Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)..........		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80

Impervious areas:

Paved parking lots, roofs, driveways, etc. (excluding right-of-way).		98	98	98	98

Streets and roads:

Paved; curbs and storm sewers (excluding right-of-way)...................................		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89

Western desert urban areas:

Natural desert landscaping (pervious areas only)[4]...		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders).		96	96	96	96

Urban districts:

Commercial and business.........................	85	89	92	94	95
Industrial..	72	81	88	91	93

Residential districts by average lot size:

1/8 acre or less (town houses).....................	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

Developing urban areas

Newly graded areas (pervious areas only, no vegetation)[5]...................................		77	86	91	94

Idle lands (CN's are determined using cover types similar to those in table 2-2c).

[1]Average runoff condition, and $I_a = 0.2S$.

[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

TABLE 205-2: Runoff Curve Numbers for Urban Areas
(SOURCE: 210-VI-TR-55, Second Ed., June 1986)

Cover description			Curve numbers for hydrologic soil group—			
Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1]Average runoff condition, and $I_a = 0.2S$.
[2]Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
[3]Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.
  Poor: Factors impair infiltration and tend to increase runoff.
  Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

TABLE 205-3: Runoff Curve Numbers for Cultivated Agricultural Lands
(SOURCE: 210-VI-TR-55, Second Ed., June 1986)

Runoff curve numbers for other agricultural lands[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[4]30	48	65	73
Woods—grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

[1]Average runoff condition, and $I_a = 0.2S$.

[2]*Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3]*Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4]Actual curve number is less than 30; use CN = 30 for runoff computations.

[5]CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

[6]*Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

TABLE 205-4: Runoff Curve Numbers for Other Agricultural Lands
(SOURCE: 210-VI-TR-55, Second Ed., June 1986)

Project _____   By _____   Date _____

Location _____   Checked _____   Date _____

Circle one: Present Developed   _____

1. Runoff curve number (CN)

Soil name and hydrologic group	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1]			Area ☐ acres ☐ mi^2 ☐ %	Product of CN x area

[1] Use only one CN source per line.   Totals =

$$CN \text{ (weighted)} = \frac{total\ product}{total\ area} = \underline{\quad} = \underline{\quad\quad} ;\quad Use\ CN = \boxed{\quad\quad}$$

FIGURE 205-1: Composite Curve Number Computation Worksheet
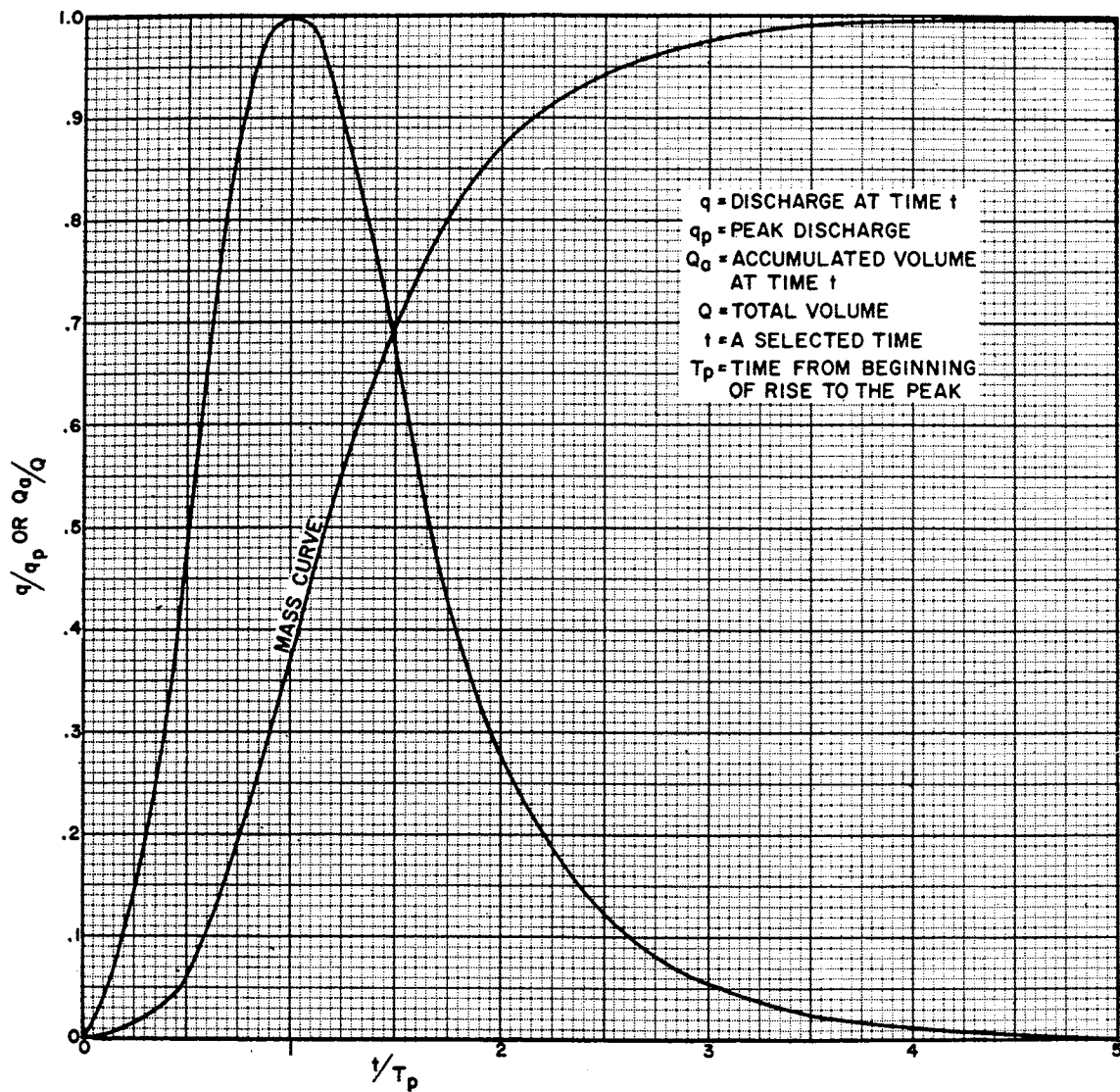(SOURCE: 210-VI-TR-55, Second Ed., June 1986)

FIGURE 205-2: Dimensionless Unit Hydrograph and Mass Curve
(SOURCE: SCS National Engineering Handbook, Chapter 4 [NEH-4])

Time Ratios (t/T_p)	Discharge Ratios (q/q_p)	Mass Curve Ratios (Q_a/Q)
0.0	0.000	0.000
0.1	0.030	0.001
0.2	0.100	0.006
0.3	0.190	0.017
0.4	0.310	0.035
0.5	0.470	0.065
0.6	0.660	0.107
0.7	0.820	0.163
0.8	0.930	0.228
0.9	0.990	0.300
1.0	1.000	0.375
1.1	0.990	0.450
1.2	0.930	0.522
1.3	0.860	0.589
1.4	0.780	0.650
1.5	0.680	0.705
1.6	0.560	0.751
1.7	0.460	0.790
1.8	0.390	0.822
1.9	0.330	0.849
2.0	0.280	0.871
2.2	0.207	0.908
2.4	0.147	0.934
2.6	0.107	0.953
2.8	0.077	0.967
3.0	0.055	0.977
3.2	0.040	0.984
3.4	0.029	0.989
3.6	0.021	0.993
3.8	0.015	0.995
4.0	0.011	0.997
4.5	0.005	0.999
5.0	0.000	1.000

TABLE 205-5: Unit Hydrograph Ordinates
(SOURCE: SCS National Engineering Handbook, Chapter 4 [NEH-4])